CLAIMS

What is claimed is:

1. A method for determining a geomagnetic transmission function for the transmission of a population of particles, said particles having one or more rigidities, to a satellite in a known earth orbit, under known geomagnetic conditions, comprising the steps:

(A) dividing said orbit into a plurality of sequential steps comprising at least a first step and a last step, each sequential pair of said steps being connected at a point, each of said points corresponding to a position of said satellite along said orbit, and specifying a value for Kp and a value for Dst to specify said geomagnetic conditions;

(B) for a plurality of said points, selecting a plurality of arrival directions for the arrival of said particles at said satellites, wherein each of said arrival directions represents either an allowed or a forbidden trajectory of one of said particles; and

(C) for each of said arrival directions at each of said plurality of said points, determining whether said arrival direction represents an allowed or a forbidden trajectory by tracing a path of said particle to arrive at said point with said arrival direction, until said particle path intersects a boundary of earth's magnetosphere, thereby indicating an allowed trajectory, or until said particle path intersects either earth's atmosphere or earth's surface, thereby indicating a forbidden trajectory, wherein said tracing of said path is performed by integrating in the time domain the Lorentz equation

$$\mathbf{F} = m\gamma \, d\mathbf{v}/d(-t') = -Q\mathbf{v} \times \mathbf{B}$$

wherein $\mathbf{F}$ is the force vector acting on said particle, m is mass, γ is $1/(1-\mathbf{v}^2/c^2)^{-1/2}$, $\mathbf{v}$ is said particle's velocity vector, t' is the travel time of said particle, Q is the charge of said particle, and $\mathbf{B}$ is the magnetic field vector acting on said particle, wherein $\mathbf{B}$ is given by

$$\mathbf{B} = \mathbf{B}_{IGRF}(\mathbf{r}, t') + \mathbf{B}_{TSYG}(Kp, \mathbf{r}, t')$$

wherein $\mathbf{B}_{IGRF}$ is the International Geomagnetic Reference Field promulgated by the International Association of Geomagnetism and Aeronomy, and $\mathbf{B}_{TSYG}$ is the modified Tsyganenko field given by the sum of $\mathbf{B}_{Xmg}{}^{(T)} + \mathbf{B}_{Ymg}{}^{(T)} + \mathbf{B}_{Zmg}{}^{(T)} + \mathbf{B}_{Xmg}{}^{(RC)} + \mathbf{B}_{Ymg}{}^{(RC)} + \mathbf{B}_{Zmg}{}^{(RC)} + \mathbf{B}_{Xsm}{}^{(C)} + \mathbf{B}_{Ysm}{}^{(C)} + \mathbf{B}_{Zsm}{}^{(C)} + \mathbf{B}_{Xsm}{}^{(M)} + \mathbf{B}_{Ysm}{}^{(M)} + \mathbf{B}_{Zsm}{}^{(M)}$, wherein coordinates in the solar magnetospheric system are denoted sm, and wherein coordinates in the solar magnetic coordinate system are denoted mg; and wherein

$\mathbf{B}_X{}^{(T)} = Q_t \, x \, z_r;$

$\mathbf{B}_Y{}^{(T)} = Q_t \, y \, z_r;$

$$\mathbf{B}_z(T) = \frac{W(x,y)}{S_T}\left(C_1 + C_2\frac{a_T + \xi_T}{S_T^2}\right) + \frac{x\frac{\partial W}{\partial x} + y\frac{\partial W}{\partial y}}{S_T + a_T + \xi_T} \times$$
$$(C_1 + C_2/S_T) + \mathbf{B}_X(T)\frac{\partial z_s}{\partial x} + \mathbf{B}_Y(T)\frac{\partial z_s}{\partial y} - Q_T D_T\left(x\frac{\partial D_T}{\partial x} + y\frac{\partial D_T}{\partial y}\right)$$

wherein $W(x,y) = 0.5\left(1 - \frac{x - x_0}{\left[(x - x_0)^2 + D_x^2\right]^{1/2}}\right) \times \left(1 + {y^2}/{D_y^2}\right)^{-1}$

wherein $Q_T = \frac{W(x,y)}{\xi_T S_T}\left[\frac{C_1}{S_T + a_T + x_T} + \frac{C_2}{S_T^2}\right]$;

wherein $z_r = z - z_s(x,y,\psi)$,

$$z_s(x,y,\psi) = 0.5\tan\psi\left(x + R_c - \sqrt{(x + R_c)^2 + 16}\right)$$

$$- G\sin\psi \cdot y^4\left(y^4 + L_y^4\right)^{-1},$$

wherein

$$S_{T,RC} = \sqrt{\rho^2 + \left(a_{T,RC} + \xi_{T,RC}\right)^2},$$

$$\xi_{T,RC} = \sqrt{z_r^2 + D_{T,RC}^2},$$

$$D_T = D_0 + \delta y^2 + \gamma_T h_T(x) + \gamma_1 h_1(x),$$

wherein $C_1 = -98.72$ when $Kp = 0, 0^+$, $C_1 = -35.64$ when $Kp = 1^-, 1, 1^+$, $C_1 = -77.45$ when $Kp = 2^-, 2, 2^+$, $C_1 = -70.12$ when $Kp = 3^-, 3, 3^+$, $C_1 = -162.5$ when $Kp = 4^-, 4, 4^+$,

$C_1 = -128.4$ when $Kp \geq 5^-$,

wherein $C_2 = -10014$ when $Kp = 0, 0^+$, $C_2 = -12800$ when $Kp = 1^-, 1, 1^+$, $C_2 = -14588$ when $Kp = 2^-, 2, 2^+$, $C_2 = -16125$ when $Kp = 3^-, 3, 3^+$, $C_2 = -15806$ when $Kp = 4^-, 4, 4^+$, $C_2 = -16184$ when $Kp \geq 5^-$,

wherein $a_T = 13.55$ when $Kp = 0, 0^+$, $a_T = 13.81$ when $Kp = 1^-, 1, 1^+$, $a_T = 15.08$ when $Kp = 2^-, 2, 2^+$, $a_T = 15.63$ when $Kp = 3^-, 3, 3^+$, $a_T = 16.11$ when $Kp = 4^-, 4, 4^+$, $a_T = 15.85$ when $Kp \geq 5^-$,

wherein $D_0 = 2.08$ when $Kp = 0, 0^+$, $D_0 = 1.664$ when $Kp = 1^-, 1, 1^+$, $D_0 = 1.541$ when $Kp = 2^-, 2, 2^+$, $D_0 = 0.9351$ when $Kp = 3^-, 3, 3^+$, $D_0 = 0.7677$ when $Kp = 4^-, 4, 4^+$, $D_0 = 0.3325$ when $Kp \geq 5^-$,

wherein $R_c = 9.084$ when $Kp = 0, 0^+$, $R_c = 9.238$ when $Kp = 1^-, 1, 1^+$, $R_c = 9.609$, when $Kp = 2^-, 2, 2^+$, $R_c = 8.573$ when $Kp = 3^-, 3, 3^+$, $R_c = 10.06$ when $Kp = 4^-, 4, 4^+$, $R_c = 10.47$ when $Kp \geq 5^-$,

wherein $L_y = 10\ R_E$,

$$\mathbf{B}_X^{(RC)} = Q_{RC} x z_r;$$

$$\mathbf{B}_Y^{(RC)} = Q_{RC} y z_r;$$

$$\mathbf{B}_Z^{(RC)} = C_5 \frac{2(a_{RC} + \xi_{RC})^2 - \rho^2}{S_{RC}^5} + B_X^{RC} \frac{\partial z_s}{\partial x} + B_Y^{RC} \frac{\partial z_s}{\partial y} - Q_{RC} D_{RC} x \frac{\partial D_{RC}}{\partial x};$$

wherein $Q_{RC} = 3C_5 \xi_{RC}^{-1} S_{RC}^{-5} (a_{RC} + \xi_{RC})$

$$D_{RC} = D_0+\gamma_{RC}h_{RC}(x)+\gamma_1 h_1(x)$$

$$h_{T,RC} = 0.5[1+x(x^2+L^2_{T,RC})^{-1/2}],$$
$$h_1 = 0.5\{1-(x+16)[(x+16)^2+36]^{-1/2}\},$$

$$C_5(Dst) = -10220+408.5\cdot Dst$$

$\mathbf{B}_{XYZ}{}^{(C)} = C_3(F^+_{x,y,z} + F^-_{x,y,z}) + C_4(F^+_{x,y,z} - F^-_{x,y,z})$, wherein

$$\begin{Bmatrix} F^\pm_x \\ F^\pm_y \end{Bmatrix} = \pm\frac{W_c(x,y)}{S^\pm[S^\pm \pm (z\pm R_T)]}\times\begin{Bmatrix} x \\ y \end{Bmatrix},$$

$$F^\pm_z = \frac{W_c(x,y)}{S^\pm} + \left(x\frac{\partial W_c}{\partial x} + y\frac{\partial W_c}{\partial y}\right)\times\frac{1}{S^\pm \pm (z\pm R_T)},$$

$$S^\pm = [(z\pm R_T)^2 + x^2 + y^2]^{1/2},$$

$$W_c(x,y) = 0.5\left[1-\frac{x-x_{0c}}{[(x-x_{0c})^2+L^2_{xc}]^{1/2}}\right]\times(1+y^2/D^2_{yc})^{-1};$$

$\mathbf{B}_X{}^{(M)} = e^{x/\Delta x}[C_6 z\cos\psi + (C_7 + C_8 y^2 + C_9 z^2)\sin\psi]$,

$\mathbf{B}_Y{}^{(M)} = e^{x/\Delta x}[C_{10} yz\cos\psi + (C_{11}y + C_{12}y^3 + C_{13}yz^2)\sin\psi]$, and

$\mathbf{B}_Z{}^{(M)} = e^{x/\Delta x}[(C_{14} + C_{15}y^2 + C_{16}z^2)\cos\psi + (C_{17}z + C_{18}zy^2 + C_{19}z^3)\sin\psi]$,

wherein C_6 through C_{19} are given by:

Kp / C_n	$= 0,0^+$	$= 1^-,1,1^+$	$= 2^-,2,2^+$	$= 3^-,3,3^+$	$= 4^-,4,4^+$	$\geq 5^-$
C_6	1.813	2.316	2.641	3.181	3.607	4.090
C_7	31.10	35.64	42.46	47.50	51.10	49.09
C_8	-0.07464	-0.0741	-0.07611	-0.1327	-0.1006	-0.0231
C_9	-.07764	-0.1081	-0.1579	-0.1864	-0.1927	-0.1359
C_{10}	0.003303	0.003924	0.004078	0.01382	0.03353	0.01989
C_{11}	-1.129	-1.451	-1.391	-1.488	-1.392	-2.298
C_{12}	0.001663	0.00202	0.00153	0.002962	0.001594	0.004911
C_{13}	0.000988	0.00111	0.000727	0.000897	0.002439	0.003421
C_{14}	18.21	21.37	21.86	22.74	22.41	21.79
C_{15}	-0.03018	-0.04567	-0.04199	-0.04095	-0.04925	-0.05447
C_{16}	-0.03829	-0.05382	-0.06523	-0.09223	-0.1153	-0.1149
C_{17}	-0.1283	-0.1457	-0.6412	-1.059	-1.399	-0.2214
C_{18}	-0.001973	-0.002742	-0.000948	-0.001766	0.000716	-0.01355
C_{19}	0.000717	0.001244	0.0002276	0.003034	0.002696	0.001185

and wherein L_y=10.0, D_x=13.0, L_{RC}=5.0, L_T=6.30, γ_T=4.0, δ=0.010, γ_1=1.0, R_T=30.0, x_{0c}=4.0, L_{xc}^2=50.0, and D_{yc}=20.0,

and thereby determining whether said particle's trajectory intersects either the boundary of earth's magnetosphere, thereby indicating an allowed trajectory, or intersecting earth's surface or earth's atmosphere, thereby indicating a forbidden trajectory.

2. The method of claim 1, wherein said plurality of arrival directions comprises one or more randomly or pseudorandomly selected arrival directions.

3. The method of claim 1, further comprising the step:

(D) for each particle rigidity, determine what fraction of particles of that rigidity will be transmitted to said satellite.

4. The method of claim 1, wherein said plurality of points comprises a complete set of points for said orbit.

5. The method of claim 1, wherein said plurality of points comprises a set of points for a portion of said orbit.

6. A method for determining, for a given particle environment outside of earth's magnetosphere, what portion of a population of particles having one or more rigidities making up said particle environment will be transmitted to a satellite in a known earth orbit, comprising the steps:

(A) performing steps (A) through (C) of claim 1, thereby computing a geomagnetic transmission function for said population of particles; and

(B) applying said geomagnetic transmission function to said population of particles, thereby determining what portion of that population of particles will be transmitted to said satellite.

7. A method for determining, for a given particle environment outside of earth's magnetosphere, what portion of a population of particles having one or more rigidities making up said particle environment will be transmitted to a satellite in earth orbit, comprising the steps:

(A) prompting a user to specify an earth orbit;

(B) determining whether said orbit is among a group of preselected orbits, each of said orbits in said preselected group of orbits having an associated predetermined geomagnetic transmission function for a range of particle rigidities, each of said predetermined geomagnetic transmission functions having been prepared in accordance with claim 1; and

(C) for the case wherein said orbit is among said preselected group of orbits, applying said predetermined geomagnetic transmission function for said orbit to said particle environment outside earth's magnetosphere.

8. The method of claim 7, wherein said preselected group of orbits comprises a quiet shuttle orbit having a 450 km altitude and a 28.5° inclination, a disturbed shuttle orbit having a 450 km altitude and a 28.5° inclination, a quiet space station orbit having a 450 km altitude and a 51.6° inclination, and a disturbed space station orbit having a 450 km altitude and a 51.6° inclination, wherein said quiet shuttle orbit has a geomagnetic transmission function given by FIG. 4, wherein said disturbed shuttle orbit has a geomagnetic transmission function given by FIG. 5, wherein said quiet space station orbit has a geomagnetic transmission function given by FIG. 6, and wherein said disturbed space station orbit has a geomagnetic transmission function given by FIG. 7.

9. The method of claim 7, further comprising the step:

(D) for the case wherein said orbit is not among said preselected group of orbits, performing a step selected from the group consisting of (a) returning an error message to a user, and (b) computing a geomagnetic transmission function for said orbit, in accordance with the method of claim 1.

10. A method for determining a flux of a species of solar ions having a specified atomic number between 3 and 92, and a specified kinetic energy, for a satellite in a near earth orbit, comprising the steps:

(A) specifying an atomic number for solar ions for evaluation;

(B) specifying a kinetic energy for said solar ions;

(C) specifying a baseline model for said flux of solar ions, wherein said baseline model is selected from the group consisting of a worst day model, a worst week model, and a peak flux model;

(D) in the case wherein said specified atomic number is greater than 20, selecting iron as an elemental spectrum model;

(E) in the case wherein said specified atomic number is less than or equal to 20, selecting oxygen as an elemental spectrum model;

(F) looking up a value for an elemental breakpoint, wherein said elemental breakpoint is a function of said elemental spectrum model and said baseline model, and wherein said elemental breakpoint is selected from the table:

Baseline model / Elemental spectrum model	worst day or peak flux	worst week
iron	24.23 MeV/nuc	19.90 MeV/nuc
oxygen	15.94 MeV/nuc	12.89 MeV/nuc

(G) in the case wherein said baseline model is said worst week model, and said elemental spectrum model is iron, and said kinetic energy is greater than 127.93 MeV/nuc, calculating an unscaled flux, wherein said unscaled flux equals $A_{sp} \times \left(En/{}^{MeV}\!/_{nuc}\right)^{-G_{sp}}$, wherein $A_{sp} = 3.16814\times10^{6}$

$(\text{cm}^2\ \text{sr MeV/nuc})^{-1}$, $\left(En/{}^{\text{MeV}}\!/_{\text{nuc}}\right)$ is said kinetic energy, normalized to be dimensionless, and $G_{sp} = 2.861$;

(H) in the case wherein the condition recited in step (G) is not satisfied, and wherein said kinetic energy is greater than said elemental breakpoint, calculating an unscaled flux wherein said unscaled flux equals $A_3 \times EN^{\gamma si}$, wherein A_3 is a function of said elemental spectrum model and said baseline model, and wherein said A_3 is selected from the table:

Baseline model / Elemental spectrum model	worst day or peak flux in $(\text{cm}^2\ \text{sr MeV/nuc})^{-1}$	worst week in $(\text{cm}^2\ \text{sr MeV/nuc})^{-1}$
iron	0.252948×10^{10}	0.249719×10^{9}
oxygen	0.106702×10^{10}	0.667628×10^{9}

and wherein γ_{si} is a spectral index and is a function of said elemental spectrum model and said baseline model, and wherein said γ_{si} is selected from the table:

Baseline model / Elemental spectrum model	worst day or peak flux	worst week
iron	-4.52970	-3.7610
oxygen	-4.14060	-3.76850

;

(I) in the case wherein the condition recited in step (G) is not satisfied, and wherein said kinetic energy is less than or equal to said elemental breakpoint, calculating an unscaled flux wherein said unscaled flux equals $A_2\exp(-G\times En^{1/4})\times En^{1/4}$, wherein A_2 is a function of said elemental spectrum model and said baseline model, and wherein said A_2 is selected from the table:

Baseline model / Elemental spectrum model	worst day or peak flux in $(\text{cm}^2\ \text{sr MeV/nuc})^{-1}$	worst week in $(\text{cm}^2\ \text{sr MeV/nuc})^{-1}$

iron	1.8991×10^{8}	3.0372×10^{8}
oxygen	4.9518×10^{8}	1.1307×10^{9}

and wherein G_{si} is a spectral index and is a function of said elemental spectrum model and said baseline model, and wherein said G_{si} is selected from the table:

Baseline model / Elemental spectrum model	worst day or peak flux	worst week
iron	5.70	5.70
oxygen	5.70	5.70

; and

(J) in the case where said atomic number is between 3 and 92, inclusive, calculating a solar ion flux for said specified atomic number and said specified kinetic energy by multiplying said unscaled flux by a scale factor ratio, said scale factor ratio being the ratio of a scale factor for an element having said selected atomic number over a scale factor for said spectrum model element, wherein said scale factors are selected from the table:

Atomic Number	Scale Factor	Atomic Number	Scale Factor	Atomic Number	Scale Factor	Atomic Number	Scale Factor	Atomic Number	Scale Factor	Atomic Number	Scale Factor
5	0	22	4.377×10^{-3}	39	4.878×10^{-6}	56	4.878×10^{-6}	73	2.195×10^{-8}	90	4.878×10^{-8}
6	4.704×10^{-1}	23	4.088	40	1.22×10^{-5}	57	4.878×10^{-7}	74	2.439×10^{-7}	91	0
7	1.2059×10^{-1}	24	1.65×10^{-2}	41	9.756×10^{-7}	58	1.22×10^{-6}	75	4.878×10^{-8}	92	2.927×10^{-8}
8	1	25	5.625×10^{-3}	42	4.878×10^{-6}	59	1.951×10^{-7}	76	7.317×10^{-7}	3	0
9	4.560976×10^{-5}	26	1	43	0	60	9.756×10^{-7}	77	7.317×10^{-7}	4	0
10	2.1312×10^{-1}	27	1.303×10^{-2}	44	2.195×10^{-6}	61	0	78	1.463×10^{-6}		
11	1.744715×10^{-2}	28	3.172×10^{-2}	45	4.878×10^{-7}	62	2.439×10^{-7}	79	2.439×10^{-7}		
12	2.0624×10^{-1}	29	3.048×10^{-4}	46	1.463×10^{-6}	63	9.756×10^{-8}	80	2.439×10^{-7}		
13	1.826829×10^{-2}	30	7.457×10^{-4}	47	4.878×10^{-7}	64	4.878×10^{-7}	81	2.195×10^{-7}		
14	3.5935×10^{-1}	31	4.878×10^{-5}	48	1.707×10^{-6}	65	7.317×10^{-8}	82	2.439×10^{-6}		
15	2.279675×10^{-4}	32	1.22×10^{-4}	49	2.195×10^{-7}	66	4.878×10^{-7}	83	1.463×10^{-7}		
16	9.758×10^{-2}	33	7.317×10^{-6}	50	4.878×10^{-6}	67	9.756×10^{-8}	84	0		
17	1.680488×10^{-4}	34	7.317×10^{-5}	51	3.415×10^{-7}	68	2.439×10^{-7}	85	0		
18	1.771545×10^{-3}	35	9.756×10^{-6}	52	7.317×10^{-6}	69	4.878×10^{-8}	86	0		
19	3.644715×10^{-4}	36	4.878×10^{-5}	53	1.463×10^{-6}	70	1.951×10^{-7}	87	0		
20	4.826×10^{-2}	37	7.317×10^{-6}	54	6.585×10^{-6}	71	4.878×10^{-8}	88	0		
21	2.929×10^{-4}	38	2.439×10^{-5}	55	4.878×10^{-7}	72	1.951×10^{-7}	89	0		

wherein elements having atomic number of 20 or less are scaled to oxygen, and elements having higher atomic numbers are scaled to iron.

11. A method for determining a flux of solar ions of species having a range of atomic numbers between 3 and 92, wherein each of said species includes particles having a range of specified kinetic energies, for a satellite in a near earth orbit, comprising the steps:

(A) for each kinetic energy of each of said species, performing steps (A) through (K) of claim 10, and storing a flux value for each of said kinetic energies for each of said species; and

(B) adding each of said flux values to obtain a total solar ion flux value.

12. A method for modeling the effects of cosmic rays on microelectronics on a computer connected to the internet, comprising the steps:

(A) receiving a login message from a remote user connected to the internet, and generating and transmitting back to said user with a script in response thereto an HTML main menu page, wherein said main menu page comprises prompts for said user to run one or more routines selected from the group consisting of: (1) a routine for calculating a geomagnetic transmission function for SEU-inducing particles, (2) a routine for calculating a flux of SEU-inducing particles in the near earth environment or in the environment shielded by earth's magnetosphere, (3) a routine for calculating a solid shielding transport function for SEU-inducing particles, (4) a routine for calculating a proton induced single event upset rate, (5) a routine for calculating a linear energy transfer rate, and (6) a routine for calculating a heavy ion induced single event upset rate, said main menu page further comprises prompts for said user to select a user request file for each of said routines;

(B) in response to a message from said user to run at least one of said routines, using a user request file specified by said user, generating and executing with a script a system command for said

computer to run each of said specified routines; and

(C) in response to the completion of all of said routines specified by said user, generating and transmitting to said user with a script an HTML page notifying said user of said completion.

13. The method of claim 12, wherein said main menu page generated and transmitted to said user further comprises prompts for said user to create or edit a user request file for any one of said routines, in lieu of running said one or more of said routines, and further comprising the step:

(D) in response to a message from said user to create or edit a user request file, generating and transmitting to said user with a script an HTML page with prompts for the entry of fields for said user request file; and

(E) in response to said user transmitting information for said user request file, storing said information in a user request file with a script.

14. The method of claim 12, wherein said main menu page comprises prompts for said user to run a routine for calculating a geomagnetic transmission function for SEU-inducing particles, and wherein said step of generating and executing with a script a system command for said computer to run each of said specified routines comprises at least generating and executing a system command for said computer to run said routine for calculating a geomagnetic transmission function for SEU-inducing particles, in accordance with claim 1

15. The method of claim 12, wherein said main menu page comprises prompts for said user to run a routine for calculating a flux of SEU-inducing particles in the near earth environment or in the

environment shielded by earth's magnetosphere, and wherein said step of generating and executing with a script a system command for said computer to run each of said specified routines comprises at least generating and executing a system command for said computer to run said routine for calculating said flux of SEU-inducing particles in the near earth environment or in the environment shielded by earth's magnetosphere, wherein said routine comprises calculating a flux of solar heavy ions in accordance with claim 10.